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3D FEM for Sintering of Solar Cell with Boron Back Surface Field Based on Solidwork Simulation

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Abstract

Numerical simulation was carried out on the sintering process of the solar cell with boron back surface field (B-BSF) using the finite element analysis (FEA) software Solidwork Simulation, to analyze the bend problem and to obtain the distribution of residual stress. The impact was discussed on the thicknesses of silicon material and B-BSF on the bend level of the cell, and the stress state of the solar cells under different bend levels was investigated. The results reveal that the increasing sintering temperature causes increasing bow and residual stress but not remarkable, because B-BSF already has reached the yield stress to cause the plastic deformation. The thinner wafer will make the both bow and residual stress increase. When the thickness of the wafer was lower than 140 μm, there would be some damages occur near the electrode which was the location of residual stress concentration. If the thickness of wafer is below 6 μm, there may be some local damages occur in the region of the wafer near the electrode.

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Keywords: solar cell; boron back surface field; thermal stress ; finite element analysis;

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1. Introduction

In the manufacture of silicon solar cells, the most cost effective and widely used methods of applying the metallizations is the application of metal-based pastes or inks to both sides of the cell. For the metallization application, screen printing (SP) is the dominant method accounting for 90% of the world's industrial production of silicon solar cells [1]. Typical industrial silicon solar cells make use of a screen printed aluminum (Al) layer at the rear side that is cofired with the front side metallization in a belt furnace [2]. The so formed Al profile works as back surface field (Al-BSF). During the heating and cooling process, the solar cells distort in a bow shape. This is a significant problem in industry from the aspects of module assembly, reliability, and efficiency of the cells [3].The sintering process was investigated and the bow induced by different thermal expansion coefficients of Al and silicon were also investigated [4-6]. The boron back surface field (B-BSF) is one of the promising techniques for achieving high quality back contact. It has three advantages over the Al-BSF as the following: it can be formed without inducing high stress in the substrate; can be used in conjunction with a dielectric passivation to further enhance the passivation and optical properties; and can provide higher p^+ doping concentration because of its higher solid solubility limit in Si allowing better passivation to be achieved [7-9]. Since the mismatch of heat expansion coefficients between silicon and various electrode materials, such as B-BSF, the residual stresses thus caused during the sintering process have significant influence on the quality and the cost of the products. The advantage of finite element method (FEM) is that we can simulate the behaviors of structure by the true material properties. In this paper, FEM was used to simulate the sintering process of cell with B-BSF, trying to find the best composition of B-BSF and thicknesses for both the metallizations and the wafer itself.

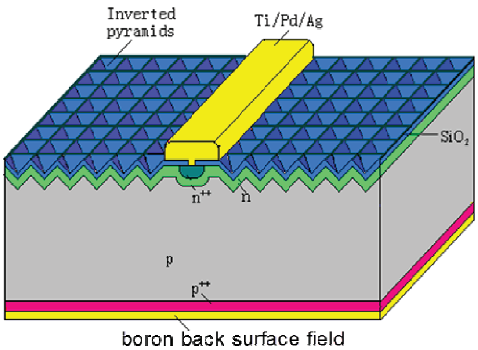

Fig. 1. The composition of solar cell with boron back surface field the geometry

2. Introduction

The work we carried out to develop a FEM model to simulate the bow and residual stress due to sintering process. The elastic-perfectly plastic model of the material is adopted for silicon and boron. It is permissible and convenient to neglect the effect of work hardening, assume that the plastic flow occurs as the stress has reached the yield stress [10]. The temperature effect is described by linear thermal expansion coefficient. There are two main material properties needed to simulate the behaviour of material in FEA model. Young's modulus E=130 GPa, Poisson's ratio ν=0.28, yield stress σ_y=120 MPa, and linear thermal expansion coefficient $\alpha=3.36\times10^{-6}$ K^{-1} for silicon, and E=130 GPa, ν=0.28, σ_y=120 MPa, $\alpha= 3.36\times10^{-6}$ K^{-1} for boron. The electrode is composed of a layer of copper sandwiched in two layers of solder, as shown in Figure 1. The area of the wafer is 156×156 mm^2 and the area of B- BSF in practice is 152 × 152 mm^2 which is little less than the area of the wafer. In order to compare the effect of the geometric parameters, a sample is given to compare other control groups and the size as follow: the thicknesses of wafer, B-BSF are 160~220 μm, 8~20 μm respectively, and sintering temperature is from 800 to 1100 °C [10]. The thickness direction was set as z-axis. The degrees of freedom (DOF), u_y, Θ_x, Θ_z on the symmetry plane are constrained. According to the shape of bow [11, 12], we set u_z as zero in the edge parallel to x-axis. In order to avoid rigid body motion in simulation, the DOF, u_x, was set zero to any node. The initial stresses in the cell were assumed zero and set the initial temperature was the sintering temperature. The simulation was completed when the temperature reached 25 °C.

3. Simulation results and Discussion

The residual stress and Von Mises stress of the sample at the sintering temperature 950 °C were shown on deformed shape in Figure 2. It could be seen the solar cell models deformed with the four corners deflecting away from the front metallization. Comparing the undeformed shape, the bow due to sintering was distinct. These images showed all four quadrants assembled together so that the overall effect could be seen. The structure was not completely symmetric as the electrical contacts of the metallizations were only on two opposite sides. In the models, the difference in maximum deflection between the adjacent sides was <3% with the smaller deflection on the sides with electrical contacts [13]. The max residual stress located in the wafer was 77.78 MPa (Figure 2(a)), 30.23 MPa (Figure 2(b)), 30.19 MPa (Figure 2(c)), and 60.33 MPa (Figure 2(d)) for first principal stress, second principal stress, third principal stress, and Von Mises stress, respectively.

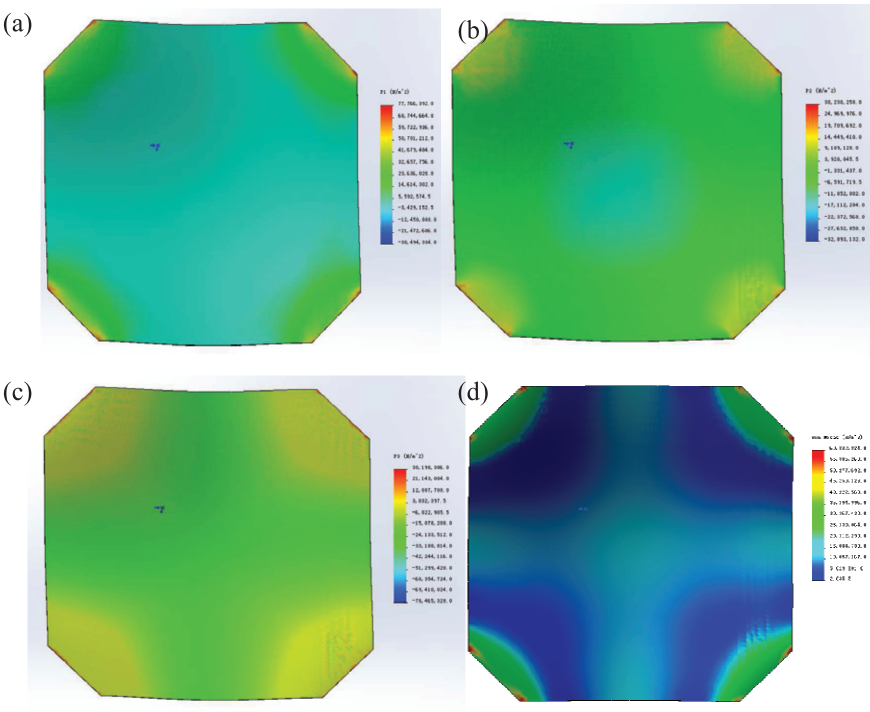

Fig. 2. The contour of the residual stress on the deformed shape and undeformed shape of the solar cell with boron back surface field;(a) first principal stress; (b) second principal stress, (c)third principal stress, (d) Von Mises stress,

The contour of the bow of the sample at the sintering temperature 950 °C was shown on deformed shape in Figure 3. It showed typical convergence behavior with the final max displacement at the center of the solar cell. This corresponded to a maximum edge displacement of 0.96 mm, and the deflection occurs the in the center of solar cell was 1.56 mm. The calculations predicted the anisotropic shrinkage arises due to this 3-D rearrangement of the boron particles during sintering. However, the bow was induced by not only the formation of B-BSF, but also the sintering of wires to the solar cells [14]. The max residual stress located in the wafer was 2.68×10^{-3} mm (Figure 3(a)), 2.69×10^{-3} mm (Figure 3(b)), 1.56 mm (Figure 3(c)), and 1.56 mm (Figure 3(d)) along X axle direction, Y axle direction, Z axle direction, and URES, respectively. It revealed that the elastic-perfectly plastic model was good enough to simulate the bow and the residual stress. The FEM model could explain the influence of sintering temperature was not remarkable when the residual stress of B-BSF have reached yield stress. The same result was investigated by experiments in reference [8-12, 15]. In future, the complex plastic model including the nonlinear behaviours could be considered in FEM.

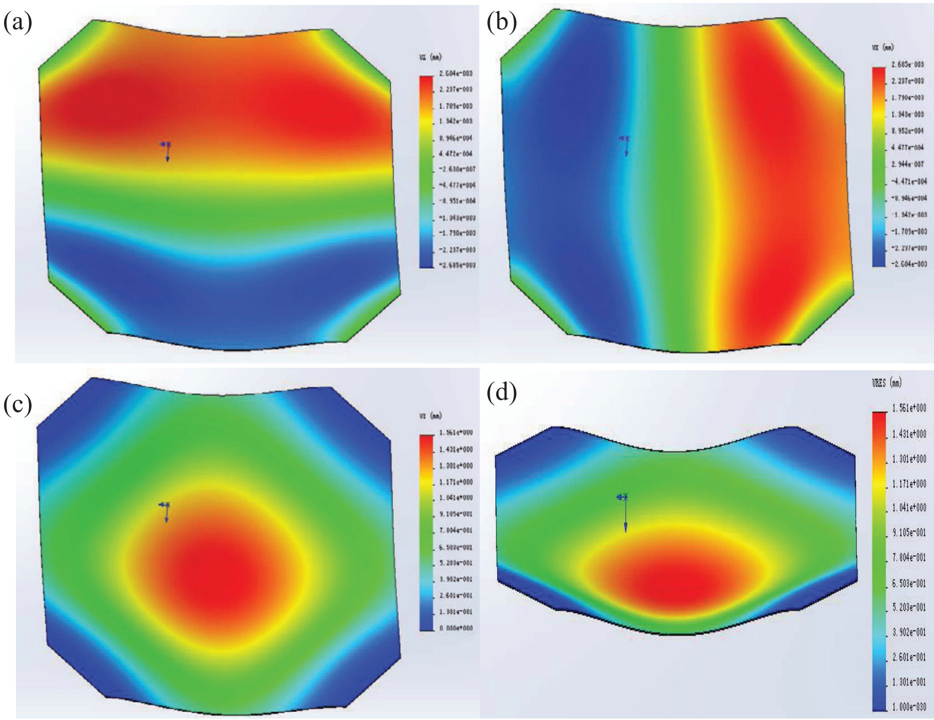

Fig. 3. The contour of the bow on the deformed shape of the solar cell with boron back surface field;(a) X axle direction; (b) Y axle direction, (c) Z axle direction, (d) URES,

The sintering temperatures were varied 800 °C to 1100 °C and the other geometric parameters were controlled the same with sample. The residual stress and bow were shown in figure 4(a). It was not remarkable for residual stress and bow increasing with the sintering temperature increasing. It was because the plastic deformation located in B-BSF. The residual stress of B-BSF has already reached the yield stress of the material, boron, 13 MPa. The result was the same as the bow due to the formation of Al-BSF [16]. The effects of the thickness of wafer and boron back surface field were investigated in this section. The thinner wafers were considered and the sintering temperature and the other parameters were fixed as 950 °C to compare the effect of the thickness of the wafer shown in Figure 4(b). There were seven cases of thickness, from 160 μm to 220 μm of wafer were studied in this section. It could be seen that with the thickness of the wafer increasing, the residual stress and bow of the wafer decreasing. When the thickness of the wafer was 160 μm, the max stress of Von Mises was 76.8 MPa and the max bow was 2.94 mm, with the deflection located at the center of solar cell. However, when the thickness of the wafer was lower than 140 μm, there would be some damages occur near the electrode which is the location of residual stress concentration. In order to reduce the costs per watt of photovoltaic power, the larger and thinner wafers were manufactured to save expensive material [17]. Therefore, the wafer bow and the residual stress in the cell were increasingly important issues avoid breakage for solar cell process development [18]. The residual stress and bow for different thickness of boron back surface field at the sintering temperature 950 °C were shown in Figure 4(c). There were seven cases of thickness, from 8 μm to 20 μm of boron back surface field, were studied. From Figure 4(c), with the increasing thickness of B-BSF, only the residual stress increase remarkable. The ratio of the increasing bow was much less than the increasing residual stress. It revealed the bow of solar cell due to sintering was dominated by B-BSF. The increasing residual stress due to the increasing thickness of B-BSF might cause the local damage of the wafer near the electrode. However, when the thickness of wafer was below 6 μm, there might be some local damages occur in the region of the wafer near the electrode from our result. The periodic potential function of the crystal for silicon wafer with thinner B-BSF might be broken on sintering process to influence the electrical properties of solar cell [19].

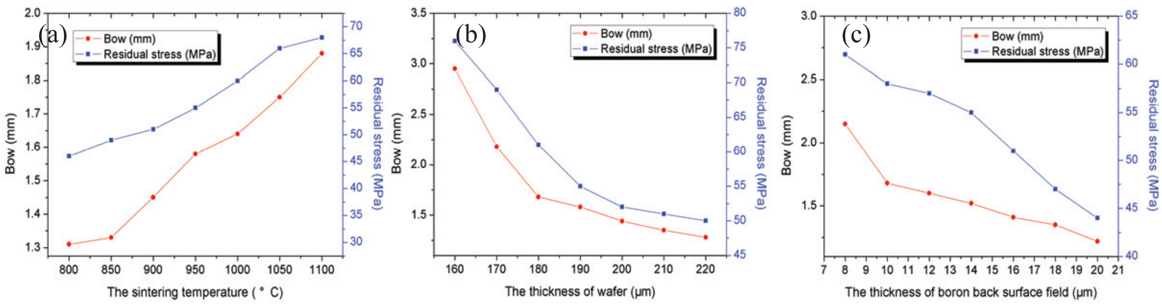

Fig. 4. (a)The residual stress and bow with the increasing sintering temperature ; (b)t he residual stress and bow with the decreasing thickness of wafer; (c)the residual stress and bow for different thickness of boron back surface field

4. Conclusion

The FEM model to simulate the bow and residual stress induced by sintering was success to explain the behaviour of solar cell during sintering. According to the results of the simulation, it reveals that the elastic-perfectly plastic model is good enough to simulate the bow and the residual stress; the decreasing thickness of wafer causes the increasing residual stress and bow; the bow is dominated by B-BSF and silicon. It is not remarkable for residual stress and bow increasing with the sintering temperature increasing; When the thickness of the wafer is lower than 140 μm, there will be some damages occur near the electrode which is the location of residual stress concentration; If the thickness of wafer is below 6 μm, there may be some local damages occur in the region of the wafer near the electrode.

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